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Temporary confinement of loose-housed hyperprolific sows reduces piglet mortality[1]

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ABSTRACT: The objective of this study was to investigate piglet mortality in a commercial setting where sows were accommodated in a loose-housed system with an option to confine the sow for a few days around farrowing and during early lactation. The study was conducted in a Danish piggery where records were obtained from 2,139 farrowings. Sows were randomly allocated to 1 of 3 treatments: loose–loose (LL), loose–confined (LC), and confined–confined (CC). In LL, sows were loose housed from the time they entered the farrowing pens to weaning. In LC, sows were loose housed until farrowing was finished and then confined to d 4 after farrowing. In CC, sows were confined at d 114 of gestation to d 4 after farrowing. All sows were loose housed from d 5 to weaning. Total piglet mortality was analyzed at batch level to include piglets fostered by nurse sows and at sow level to analyze the effects of confinement during different time periods. Total piglet mortality was greater in LL (26.0%) and LC (25.4%) compared with CC (22.1%; $P < 0.001$). The proportion of stillborn piglets was not different between treatments ($P = 0.21$) but a larger proportion was crushed in LL (10.7%) compared with LC (9.7%; $P = 0.03$), which again was greater than CC (7.8%; $P < 0.001$). Piglet mortality before equalization was lower in CC (3.7%) than in LL (7.5%) and LC (7.0%; $P < 0.001$). Confinement reduced mortality from litter equalization to d 4 (7.6% for LL vs. 6.7% for LC; $P = 0.01$) but more so in CC (5.6%) than in LC ($P < 0.001$). From d 4 to weaning, LL had lower mortality (5.6%) than LC (6.9%) and CC (6.6%; $P = 0.01$). A larger proportion of sows in CC were classified as "low mortality" compared with LL and LC both before ($P < 0.001$) and after ($P = 0.002$) litter equalization. The results in this study emphasize that the period of time from the birth of the first piglet to litter equalization is important in relation to piglet mortality. The results also suggest that confinement for 4 d after farrowing can reduce mortality in this specific period, but only confinement from d 114 of gestation to d 4 after farrowing reduced total piglet mortality.

Key words: farrowing, housing, lactation, loose sows, piglet mortality, temporary crating

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INTRODUCTION

The farrowing crate is used to physically restrict the sow from moving around and thereby reduce crushing of the piglets but the restriction also prevents the sows from performing behaviors associated with nest building, farrowing, and lactation (Damm et al., 2003; Jarvis et al., 2004). The negative impact on sow welfare has led to the development of alternatives such as designed farrowing pens (Baxter et al., 2012), but variability and inconsistency in piglet mortality has limited commercial uptake of these systems (Arey, 1997; Baxter et al., 2012). Piglet deaths mainly occur in the first days of life (Marchant et al., 2000),

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indicating that piglets need protection in this period. Confinement of sows in early lactation can reduce piglet mortality compared with loose-housed sows (Moustsen et al., 2013; Hales et al., 2015), but the pens in these studies did not contemplate the design criteria proposed for loose farrowing and lactating sows by Baxter et al. (2011). Consequently, the sow welfare and piglet protection (**SWAP**) pen was developed by incorporating a confinement option into a designed farrowing pen for loose sows. Genetic improvements have increased litter size, for example, in Denmark, where average litter size is 16.6 total born piglets (Rutherford et al., 2013). Large litters require management interventions such as the use of nurse sows for surplus piglets to successfully rear all piglets (Baxter et al., 2013). Studying piglet mortality should, therefore, be conducted not only on sow level but also on batch level and include piglets reared by nurse sows and moved between sows. Assessment of piglet mortality is, therefore, best studied in commercial settings. The objective of this study was to investigate piglet mortality in a commercial setting where sows were housed in a system with an option to confine the sow. The hypothesis tested was that confinement of sows for 4 d after farrowing in SWAP pens would reduce piglet mortality compared with loose-housed sows.

MATERIALS AND METHODS

The study was conducted in a newly constructed 1,250 sow piggery (Krannestrup, Mejlby, Denmark) with Danish Landrace × Danish Yorkshire sows farrowing in weekly batches. The piggery had been in operation for 3 mo when the data collection started. All procedures involving animals were conducted in accordance with the guidelines of the Danish Ministry of Justice with respect to animal experimentation and care of animals under study.

Experimental Design

Sows were allocated to 1 of 3 treatments: loose–loose (**LL**), loose–confined (**LC**), or confined–confined (**CC**; Fig. 1). Sows in LL were loose housed from entry to the farrowing unit to weaning after 4 wk of lactation. In LC, sows were loose housed from entry to completion of farrowing (birth of placenta). At first observation of completed farrowing, sows were confined until d 4 after farrowing. In CC, sows were loose housed at entry and confined from d 114 of gestation until d 4 after farrowing. On d 4, the confinement was removed and sows in LC and CC were loose housed for the remaining of lactation.

First parity sows were randomly allocated to 1 of the 3 treatments to assure an equal distribution across treatments and would (as much as possible) return to the same system for the following farrowings. Batches of first parity sows were, furthermore, grouped together according to expected farrowing dates (to facilitate cross-fostering within treatments) and the farrowing date groups were then randomly allocated to 1 of the 3 treatments.

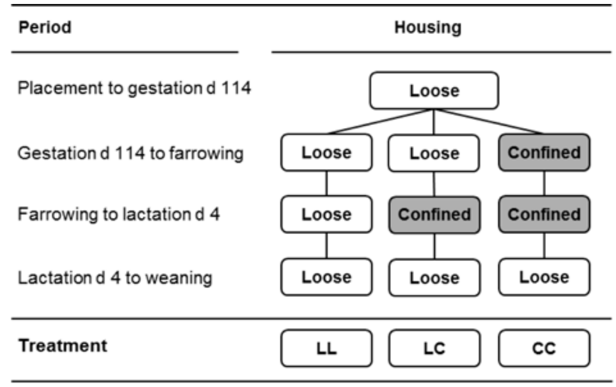

Figure 1. Illustration of the experimental design. LL = loose–loose; LC = loose–confined; CC = confined–confined.

Housing

During mating and gestation, sows were housed in stable groups of 50 to 60 sows corresponding to the size of a weekly batch. Sows were moved to the farrowing unit where they were placed in individual SWAP pens 4 to 7 d before expected farrowing. The farrowing unit consisted of 5 identical rooms, each with 58 farrowing pens, and 2 buffer sections with 29 farrowing pens each. The desired room temperature in the farrowing unit was 18 to 21°C. This was controlled via diffuse ventilation with supplemental air inlets in the ceiling in combination with partial pit ventilation. Artificial light was on from 0700 to 1600 h in all farrowing rooms.

The SWAP pens (Fig. 2) measured 210 by 300 cm and the flooring consisted of 60% solid concrete floor and 40% cast iron slats (>40% void). The concrete floor was equipped with 3 different circuits for floor heating: 1 in the creep area for the piglets, 1 in the resting area for the sow, and 1 in the inspection aisle to prevent heat loss from the creep. The creep was placed adjacent to the aisle and had an adjustable lid. The trough and drinker for the sow was placed next to the creep and there was a piglet drinker above the slatted floor. All pens were fitted with a straw rack on the gate and a sloped wall in the intended resting area to support the sow when lying down (Damm et al., 2006) as well as an open (barred) pen partition from the sloping wall to the back wall to facilitate dunging behavior. The pens had farrowing rails on the back wall and on the wall between the trough and the back

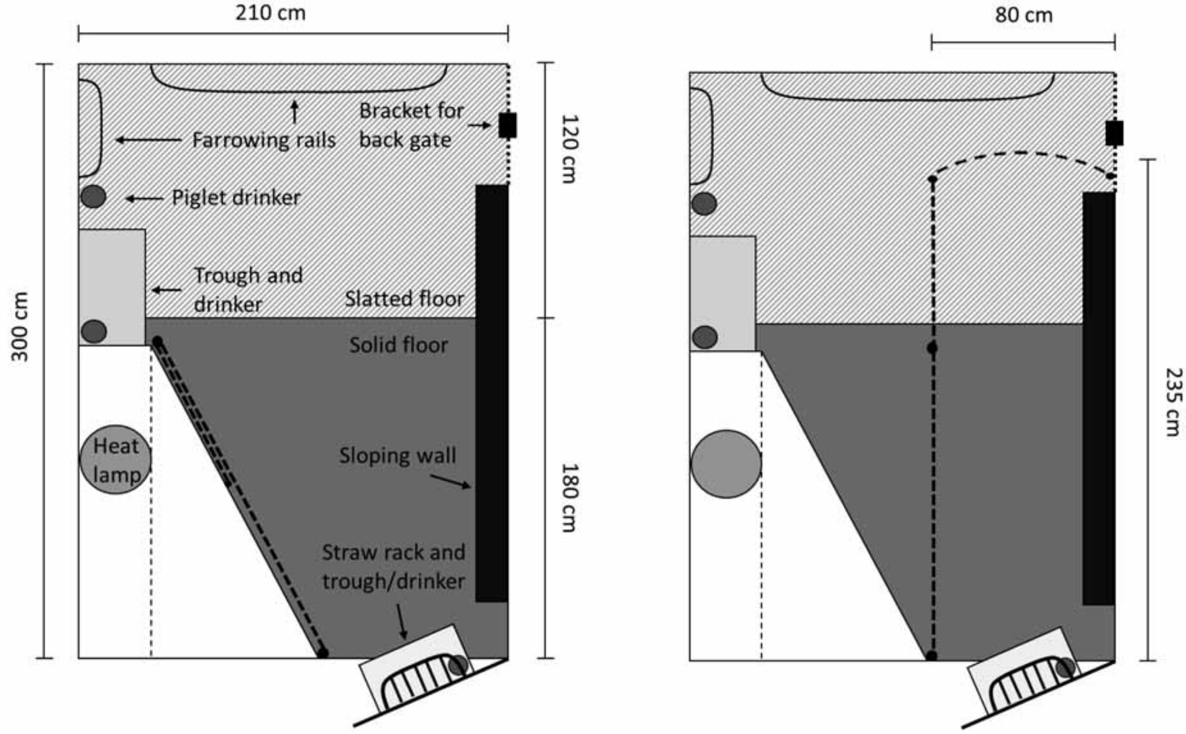

Figure 2. Design of sow welfare and piglet protection pen when sow is loose (left) and confined temporarily (right). Gray space = solid concrete floor, diagonal lines = slatted metal floor, white area = covered creep area with heat lamp, black space = sloping wall, and dashed outer line = open pen wall/vertical bars

wall. The front of the creep formed a swing-side that was hinged on the front wall of the pen and folded out to form the option of temporary confinement with the sloped wall as the opposite side. The swing-side was made up of 2 metal frames with horizontal bars and 7 vertical "fingers" at the bottom. A back gate was placed in a bracket between the pens. An additional trough and drinker was placed on the gate to provide feed and water when the sows were confined.

In the first days after parturition, saw dust was spread in the creep area as bedding material, and for the first 4 d of lactation, a 150-W heat lamp was provided in the covered part of the creep area. Floor heat (approximately 42°C) in all areas was on when the sows entered the pens. Heat in the sow area was generally on for 4 d after the main day of farrowing whereas the floor heat in the creep area and the aisle was on from insertion to weaning.

Animals and Management

All animals in this study were managed according to the general routines of the herd. The study involved 1,125 sows of parity 1 to 4. All sows were artificially inseminated with production semen from Duroc boars (Hatting KS, Horsens, Denmark) and fed in agreement with Danish recommendations (Tybirk et al., 2014). In the gestation period, the animals were fed once a day in electronic sow feeders according to parity and body condition. The gestation diet was based on wheat, barley, and soybean meal and contained 8.2 MJ potential physiological energy/kg feed (Boisen, 2001) and 5.3 g standardized ileal digestible Lys/kg feed. In the farrowing unit, sows were fed a lactation diet 3 times per day (0730, 1230, and 1530 h). The lactation diet was based on barley, wheat, and soybean meal and contained 8.7 MJ potential physiological energy/kg feed (Boisen, 2001) and 7.5 g standardized ileal digestible Lys/kg feed. Before farrowing, the sows received a total of 3.7 kg feed/d. The ration was reduced to 2.7 kg/d 2 d before expected farrowing and increased to 3.2 kg feed/d on d 2 after farrowing. The following days, the feed ration was increased by 0.5 kg feed/d to d 6 and thereafter by 0.5 kg feed/d every second day, provided that sows had emptied the troughs. After approximately 14 d, the number of feeding times was increased to 5 times per day (0730, 1030, 1230, 1530, and 2030 h). Sows and piglets had ad libitum access to water via drinking nipples throughout the period from placement in the farrowing pens to weaning.

Straw was provided in straw racks from placement of sows in the farrowing pens to weaning. Staff was generally present from 0700 to 1600 h every day and performed regular rounds through the farrowing unit to inspect sows that had farrowed. Obstetric aid was performed when deemed necessary. On d 1, piglets were inspected, dry umbilical cords were cut off, and piglets were injected with 0.5 mL antibiotics (Clamoxyl Prolongatum; Orion

Pharma Animal Health, Nivaa, Denmark). Litters were equalized within treatments to 13 to 14 piglets by cross-fostering piglets born within the same 12 to 24 h when it had been ensured that all piglets had consumed colostrum. In general, the biggest and smallest piglets were removed from the litters. Within treatment, small piglets were gathered in a litter where the majority of piglets were small and surplus (larger) piglets were allocated to nurse sows. Nurse sows were used according to a 2-step nurse sow scheme (Baxter et al., 2013) where the surplus newborn piglets were moved to a sow with 4- to 8-d-old piglets. The 4- to 8-d-old piglets were moved to a sow with 21-d-old piglets and the 21-d-old piglets were weaned. Nurse sows within each treatment were selected based on their performance and body condition.

On the first 2 d after farrowing, piglets were closed inside the creep area during feeding. Tail docking, the injection of iron (Solofer; Vitfoss, Gråsten, Denmark) mixed with pain relief (0.2 mL per pig, Melovem; Salfarm Danmark, Kolding, Denmark), oral administration of Baycox (Bayer A/S, Copenhagen, Denmark), and surgical castration were all performed on d 3. Piglets were weaned from the sow at 4 wk. Piglets that were traumatized or diseased, or for other reasons deemed unable to survive to weaning, were euthanized.

Records

The date of insertion in the farrowing unit, the date and time of the first observation of farrowing, and the number of live-born and stillborn piglets as well as date and time of closing and opening of confinement was noted on a sow card. If obstetric aid was performed or if sows were treated with antibiotics, it was also recorded on the sow card. When litters were equalized, the date and time of the procedure was recorded as well as the size of the litter when the procedure was completed. Dead piglets were collected from each sow on a daily basis. At collection, dead piglets from the same pen were bagged together with an ear tag and date and tag number was recorded on the sow card. If piglets were moved between sows, within treatment, the number removed or added was noted. Piglets that were moved to a nurse sow were tagged according to treatment, and nurse sows were housed according to the treatment the piglets came from. Thus, nurse sows for piglets from LL were loose housed and nurse sows for piglets from LC or CC were confined until the piglets were 4 d old and then loose housed from d 4 to weaning.

Postmortem Examination

All piglets that died before weaning were stored at –2°C until they were weighed and subjected to postmortem examination to confirm the cause of death. Postmortem examinations were performed on a weekly basis. Stillbirth was determined by inflation of the lung tissue. If the lung tissue would not float in water the piglet was categorized as "stillborn." Piglets were categorized as "crushed" if there were obvious signs of trauma or subcutaneous edema or both in any part of the body. Live-born piglets that did not display signs of crushing and had not received colostrum as well as piglets that were euthanized by the staff were classified as "euthanized or weak." Piglets that died from disease and piglets that could not be accurately classified at the postmortem examination were categorized as dead from "other causes." The stomach contents of the dead piglets were evaluated as "empty," "less than half full," "more than half full," and "full."

Statistical Analyses

Statistical analyses were performed using SAS version 9.3 (SAS Inst. Inc., Cary, NC) with batch or sow as the experimental unit. Statistical significance was accepted at $P < 0.05$ and $P < 0.10$ was considered a trend. For analyses of system performance on batch level, the number of farrowings, total born piglets, percent stillborn piglets, percent of piglets fostered by nurse sows in a batch (piglets fostered by nurse sows/live born), total mortality ((stillborn + live born dead)/total born), live-born mortality (live born dead/live born), and percent crushed piglets (crushed/total born) were analyzed using the MIXED procedure of SAS with treatment (LL, LC, or CC) as fixed effect and batch as random effect. The distributions of cause of death in the 3 treatments (LL, LC, and CC) were analyzed using a χ^2 test. Percent live-born piglets that died with empty stomachs (empty stomach/necropsied piglets) was analyzed by use of the GLIMMIX procedure with an underlying binomial distribution and treatment (LL, LC, or CC) as fixed effect and batch as random effect.

Analysis of sow performance was conducted on the farrowing sows. Sow parity was analyzed with treatment as fixed effect and batch as random term. Data on total born, live born, equalized litter size, and weaned piglets were normally distributed and analyzed using the MIXED procedure with treatment (LL, LC, or CC), parity (parity 1, parity 2, or parity 3 to 4), and the corresponding interaction term as fixed effects and batch as random effect. The number of stillborn piglets per litter was discrete and analyzed using the GLIMMIX procedure to fit a linear model with an underlying Poisson distribution and treatment and parity as fixed effects, batch as random term, total born as covariate, and the corresponding interaction terms. Piglet mortality before equalization (live-born piglets that

Table 1. Performance results on batch level for loose-housed sows and sows that had been confined for the first 4 d of lactation according to 2 different strategies of confinement. Values are presented as estimates ± SE.

Item	Loose–loose	Loose–confined	Confined–confined	SE	*P*-value
Batches, no.	58	56	59		
Farrowings/batch	12.0	11.8	11.5	0.18	0.10
Total born, no./batch	213.6	218.3	210.2	4.18	0.29
Piglets fostered by nurse sows, %	18.9[a]	21.1[b]	19.7[ab]	0.97	0.04
Total mortality,[1] %	26.0[a]	25.4[a]	22.1[b]	0.64	<0.001
Stillborn,[2] %	5.8	5.2	5.2	0.35	0.21
Crushed piglets,[2] %	10.7[a]	9.7[b]	7.8[c]	0.53	<0.001
Live-born mortality,[1] %	21.4[a]	21.4[a]	17.9[b]	0.57	<0.001

[a,b]Values with different superscripts differ significantly ($P < 0.05$).

[1]Total mortality = (stillborn + live born dead)/total born, live-born mortality = live born dead/live born.

[2]Calculated as percent of total born.

died before equalization/live born), from equalization to d 4 (live born that died from equalization to d 4/ equalized litter size), and from d 4 to weaning (live born that died from d 4 to weaning/equalized litter size) was analyzed by use of the GLIMMIX procedure for binomially distributed data and treatment, parity, and the interaction term as fixed effects; batch as random term; and a litter size indicator (total born for analysis before litter equalization and equalized litter size after equalization) as covariate. Sows were categorized as "low mortality" or "high mortality" according to the mortality rate before litter equalization and from equalization to d 4. Sows were considered low mortality if they had 0 to 1 dead piglets and high mortality if they had 2 or more dead piglets. The proportion of low mortality sows in each of the 2 periods were analyzed in a linear model by use of the GLIMMIX procedure with an underlying binomial distribution and treatment and parity as fixed effect, a litter size indicator (total born for analysis before litter equalization and equalized litter size after equalization) as covariate, and the corresponding interaction terms and batch included as random term. Nonsignificant interaction terms ($P > 0.05$) were removed from the models. Results on normally distributed data are presented as estimates ± SE and results on Poisson and binomially distributed data are presented as back-transformed estimates with 95% confidence interval (**CI**).

RESULTS

The results of this study are presented at production system level and sow level. At production system level, all piglets born, incorporating surplus piglets fostered by nurse sows, were included to allow for comparison of total piglet mortality between the 3 production systems, LL, LC, and CC. In 4 batches out of 59, 1 of the treatments had to be excluded from the analyses of production systems due to insufficient quality of the data.

Results on effects of confinement during different time periods and the effects of sow factors (parity and litter size) are subsequently presented at sow level (sow performance). For the analyses of sow performance, 131 sow cards were excluded because of insufficient data quality. Sows in CC were confined on d 114.1 ± 0.01 of gestation and were confined for 72.1 ± 1.14 h before farrowing. Sows in CC stayed confined for 96.3 ± 0.55 h after farrowing and, consequently, the total time in confinement for CC sows was 168.4 ± 1.22 h. Sows in LC were confined at 2.1 ± 0.05 h after farrowing was finished and were confined for a total of 95.0 ± 0.57 h.

Production System Performance

Results on production system performance are presented in Table 1. There were 11.8 ± 0.10 farrowings and the number of total born piglets averaged 213.9 ± 2.42 piglets per batch with no difference between treatments ($P = 0.29$). Approximately 20% of live-born piglets in a batch were fostered by nurse sows. In LL, the ratio of piglets that were fostered by nurse sows was smaller than the proportion fostered by nurse sows in LC (18.9% vs. 21.1%; $P < 0.01$). Total piglet mortality was reduced in CC compared with LL and LC ($P < 0.001$). The percent stillborn piglets did not differ between treatments (5.4 ± 0.20; $P = 0.21$), but percent crushed piglets (of total born) was greater in LL compared with LC ($P = 0.03$) and further decreased from LC to CC ($P < 0.001$). Live-born piglet mortality followed the pattern of total mortality with lower mortality in CC compared with LL and LC ($P < 0.001$). The distribution of cause of death of live-born piglets that died before weaning differed between treatments ($P < 0.001$). In all treatments, the majority of live-born deaths were attributed to "crushing" (59.5% in LL, 55.3% in LC, and 53.9% in CC) followed by "other" (21.2% in LL, 23.1% in LC, and 27.2% in CC) and "euthanized/weak" (19.3% in LL, 21.6% in LC, and 18.9% in CC). More than half of live-born deaths were

Table 2. Reproduction and piglet mortality for loose-housed sows and sows that had been confined for the first 4 d of lactation according to 2 different strategies of confinement. Values are presented as estimates ± SE or back-transformed estimates and 95% confidence interval

Item	Loose–loose	Loose–confined	Confined–confined	SE	*P*-value
Number of sows	682	668	658		
Parity	2.2	2.2	2.2	0.09	0.18
Gestation length, d	116.8	116.8	116.9	0.06	0.32
Litter size, no					
Total born	17.7	18.1	17.9	0.15	0.06
Live born	16.6[a]	17.1[b]	17.0[b]	0.14	0.01
Stillborn	1.0[a] (0.9–1.1)	0.9[b] (0.8–1.0)	0.9[b] (0.8–0.9)	–	0.03
Equalized litter size	13.7	13.7	13.8	0.07	0.06
Piglet mortality,[1] %					
Before litter equalization	7.5[a] (6.8–8.1)	7.0[a] (6.4–7.7)	3.7[b] (3.3–4.1)	–	<0.001
Equalization to d 4	7.6[a] (7.0–8.3)	6.7[b] (6.1–7.4)	5.6[c] (5.1–6.2)	–	<0.001
Day 4 to weaning[2]	5.6[a] (5.0–6.2)	6.9[b] (6.0–7.4)	6.6[b] (5.9–7.4)	–	0.01

[a–c]Values with different superscripts differ significantly ($P < 0.05$).

[1]Calculated as percent of live born before litter equalization and percent of equalized litter size after litter equalization.

[2]Results from sows that were weaned at 4 wk ($n = 552$ in loose–loose, $n = 492$ in loose–confined, and $n = 416$ in confined-confined).

Table 3. Percentage of low mortality sows when sows had been loose-housed or confined for the first 4 d of lactation according to 2 different strategies of confinement. Values are presented as estimates and 95% confidence interval

Item	Loose–loose	Loose–confined	Confined–confined	*P*-value
Number of sows	682	668	658	
Low mortality sows,[1] %				
Before litter equalization	66.0[a] (61.8–70.0)	67.3[a] (63.1–71.2)	84.9[b] (81.7–87.7)	<0.001
After litter equalization to d 4	70.1[a] (65.6–74.1)	73.8[a] (69.5–77.8)	79.3[b] (75.3–82.8)	0.002

[a,b]Values with different superscripts differ significantly ($P < 0.05$).

[1]Low mortality sows = sows with 0 to 1 dead piglets in the studied period of time.

associated with empty stomachs but more so ($P < 0.001$) in LC, where 60.5% (95% CI 57.9–63.0) of autopsied piglets had empty stomachs, compared with LL and CC, where 53.3% (95% CI 50.7–55.9) and 52.7% (95% CI 49.9–55.5), respectively, had empty stomachs.

Sow Performance

Results on individual sow performance are presented in Tables 2 to 4. The average parity of the farrowing sows was 2.3 ± 0.02 with a gestation length of 116.8 ± 0.03 d. Total born litter size averaged 18.3 ± 0.07 piglets per litter. Unexpectedly, sows in LL had fewer live-born piglets than sows in LC ($P = 0.005$) and CC ($P = 0.044$) and sows in LL had more stillborn piglets per litter than sows in LC ($P = 0.027$) and CC ($P = 0.016$). Treatment tended to influence the size of the equalized litter (13.7 ± 0.03; $P = 0.06$), however, with a difference of only 0.1 piglet/litter. Piglet mortality before litter equalization was greater in LL and LC compared with CC ($P < 0.001$). Treatment also influenced mortality from equalization to d 4 ($P < 0.001$) where LL had a greater mortality rate than LC ($P = 0.01$), which again had a greater mortality than CC ($P = 0.002$). Mortality from d 4 to weaning was greater in the treatments where sows had been confined (LC and CC) compared with LL ($P = 0.01$). The number of weaned piglets per sow was calculated for the subsample of sows that fostered their own litter until the piglets were 4 wk old ($n = 552$ in LL, $n = 492$ in LC, and $n = 416$ in CC). The sows that were weaned at 4 wk in LL weaned more piglets compared with LC (11.4 ± 0.10 in LL and 11.1 ± 0.10 in LC; $P = 0.01$). Weaned piglets per litter in CC (11.3 ± 0.11) did not differ from LL or LC. A greater proportion of sows in CC were categorized as "low mortality" compared with LL and LC before litter equalization ($P < 0.001$) as well as from equalization to d 4 ($P = 0.002$).

With increasing parity, the number of total born piglets ($P < 0.001$), live-born piglets ($P < 0.001$), and stillborn piglets ($P < 0.01$) increased and the number of stillborn deaths also increased with increasing litter size ($P < 0.001$). Equalized litter size decreased with increasing parity ($P = 0.001$) but increased with increased number of live born ($P < 0.001$). Mortality before equalization was not affected by parity ($P = 0.08$) but increased with increasing number of live born ($P < 0.001$). From equalization to d 4, mortality increased with increasing parity ($P < 0.001$) and parity 2 sows tended to have a lower mortality from d 4 to weaning than sows of parity 1 and parity 3 to 4 ($P < 0.10$). Furthermore, from d 4 to weaning mortality increased with increasing size of the equalized litter ($P < 0.001$). The proportion of "low mortality" sows decreased with increasing litter size before litter equalization ($P < 0.001$) and with increasing equalized litter size ($P < 0.001$) after equalization.

DISCUSSION

The main objective of this study was to investigate piglet mortality in a system where sows could be confined for a few days after farrowing compared with loose-housed sows. In general, the results showed that confinement from gestation d 114 to d 4 after farrowing

Table 4. Effects of sow parity on reproduction and piglet mortality. Values are presented as estimates ± SE or back-transformed estimates and 95% confidence interval

Item	Parity 1	Parity 2	Parity 3+	SE	*P*-value
Number of sows	410	744	854		
Litter size, no					
Total born	16.2[a]	18.0[b]	19.4[c]	0.17	<0.001
Live born	15.5[a]	17.1[b]	18.0[c]	0.16	<0.001
Stillborn	0.8[a] (0.7–1.0)	0.8[a] (0.8–0.9)	1.1[b] (1.0–1.2)	–	0.001
Equalized litter size	13.9[a]	13.7[b]	13.5[c]	0.08	0.001
Piglet mortality,[1] %					
Before litter Equalization	6.5 (5.5–7.5)	5.4 (4.9–6.0)	5.6 (5.0–6.4)	–	0.08
Equalization to d 4	5.3[a] (4.6–6.1)	6.9[b] (6.2–7.6)	7.9[c] (7.2–8.6)	–	<0.001
Day 4 to weaning[2]	6.7 (5.8–7.8)	5.6 (4.9–6.3)	6.5 (5.8–7.3)	–	0.08

[a–c]Values with different superscripts differ significantly ($P < 0.05$).

[1]Calculated as percent of live born before litter equalization and percent of equalized litter size after litter equalization.

[2]Results from sows that were weaned at 4 wk (n = 342 for parity 1, n = 547 for parity 2, and n = 571 for parity 3 to 4).

reduced piglet mortality and that this reduction to a large extent was achieved because fewer piglets died before litter equalization. Confinement after farrowing did reduce mortality in some periods compared with loose-housed sows, but confining sows after farrowing did not lead to improvements in performance.

Total mortality and live-born mortality were higher in this study, even though reduced when sows were confined before farrowing, than the numbers reported in other studies concerning loose lactating sows (Weber et al., 2007; KilBride et al., 2012). However, compared with records from other Danish herds (with traditional farrowing crates) where total mortality is around 22 to 23% (Vinther, 2014), the levels in this study seem comparable, especially in the treatment where sows were confined before farrowing. The novelty of the pens (which meant that the staff had no experience with the system) could have had a negative influence on mortality in this study. Moreover, sows were relatively young because the study was conducted in a newly constructed piggery and, therefore, the sows had little experience with the system as well. Sows may get experience with a system as they get older and this may affect their behavior and performance in later parities. However, as seen in this and other studies, increased parity is also a risk factor for increased preweaning mortality (Jarvis et al., 2005; Hales et al., 2014).

However, the association between increased litter size and increased mortality is well documented (Roehe and Kalm, 2000; Weber et al., 2009; Hales et al., 2014) and the large litter size of approximately 17 live-born piglets should also be considered a risk factor in comparison with other large scale studies where the average litter size has been around 11 live-born piglets (Weber et al., 2007; KilBride et al., 2012). Consequences of large litter sizes include increased farrowing duration and greater risk of asphyxia, decreased viability of the newborn piglets, decreased birth weight, increased within-litter weight variation, and increased teat competition (Herpin et al., 1996; Wolf et al., 2008; Rutherford et al., 2013). Therefore, the consequences of large litter sizes have likely increased the proportion of newborn piglets that had increased risk of dying, and this might also explain the greater piglet mortality in this study. In addition, this highlights the importance of including all piglets when studying piglet mortality in hyperprolific sows under conditions where management interventions such as cross-fostering and the use of nurse sows is part of the normal management routines. The proportion of piglets fostered by nurse sows has not previously been reported in scientific literature, but the quantity of approximately 20% in this study corresponds to standard practice and experiences in commercial piggeries in Denmark.

Confinement from d 114 of gestation to d 4 after farrowing generated the lowest mortality. Confining sows from the end of farrowing did not benefit mortality before equalization, which was similar to reports by Moustsen et al. (2013) but in contrast to another study investigating effects of temporary confinement on piglet mortality (Hales et al., 2015). The first 2 h after onset of farrowing have been associated with more postural changes by sows and increased risk of crushing compared with the rest of the farrowing process and the time around farrowing can be considered a risky period in relation to piglet mortality (Weary et al., 1996; Pedersen et al., 2003). Moreover, for sows that finished farrowing during the night, there was a time lag from the actual end of farrowing until sows were confined. The fact that the sows that were confined after farrowing were loose housed during farrowing and, in some cases, also for a period of time after farrowing, can explain why mortality before equalization were similar to loose-housed sows. However, confinement after farrowing did reduce mortality from equalization to d 4 compared with loose-housed sows but not to the same extent as confinement before farrowing did. Previous results have also shown a reduction in piglet mortality when sows were confined for 4 d after farrowing, but none of these studies reported a difference in mortality between confinement before farrowing and confinement after farrowing (Moustsen et al., 2013; Hales et al., 2015). The option of confinement in this study was somewhat different from a traditional farrowing crate and pen design used in previous experiments but was designed to decrease the risk of crushing by protecting the piglets when the sow lay down. Crates have previously been shown to prevent the sows from performing dangerous movements or slow down the speed of these movements (Weary et al., 1996; Damm et al., 2005). In the current study, crushing accounted for more deaths in the loose-housed sows compared with the other treatments, indicating that confinement did reduce the risk of crushing. This is in accordance with other studies showing an increased risk of crushing when sows were loose housed (Weary et al., 1996; Weber et al., 2007). However, results from the postmortem examinations showed that more piglets died with empty stomachs if sows were confined after farrowing, indicating that nursings might have been affected in this treatment. Sows that were confined before farrowing had a few days to get used to the confinement whereas sows that were confined after farrowing had to get used to the confinement as well as recover from farrowing. Confinement after farrowing could be seen as an environmental disturbance, which has previously been shown to interrupt the farrowing process (Lawrence et al., 1992), but it is unknown if and how such an environmental disturbance after farrowing affects the sows.

Piglet mortality from d 4 to weaning was greater for sows that had been confined than for sows that had been loose housed. As suggested by Hales et al. (2015), confinement might protect weak piglets in a litter, which leaves them at greater risk when the sow is no longer confined. Another aspect is that due to the greater mortality to d 4, the number of piglets left in the pen was lower, which decreases the risk of crushing (Weary et al., 1998). Further studies on temporary crating of sows should include investigations into sow behavior when the sow is no longer confined to elucidate if this period should be in focus in relation to piglet mortality and for how long any alterations in behavior might be seen. It should also be noted that figures for mortality for d 4 to weaning at sow level were based only on a subsample of sows that fostered their own litter to wk 4 as piglet mortality in this period was not calculated for the sows that were used as nurse sows. Due to the large litter sizes and the use of a 2-step nurse sow scheme in this study, around 20% of sows within a batch would serve as a nurse sow. Numerically, the proportion of sows left in this subsample was smaller for sows that were confined before farrowing than sows that were confined after farrowing or loose housed. This indicates that more sows served as nurse sows if sows were confined before farrowing, which was likely due to more piglets surviving in this system. Similarly, the number weaned per sow after 4 wk of lactation was calculated only on the same subsample of sows. The results did not show a difference in the number weaned per sow between sows that were confined before farrowing and the loose-housed sows, but this figure should be interpreted with caution as it depicts only the weaning success for a subsample of sows not used as nurse sows. In the system perspective used in this study, all surviving piglets were weaned as they could not leave the treatment/system they were born in. The true weaning success of each system is, therefore, represented by the mortality figures for the 3 production systems.

A larger proportion of the sows that were confined before farrowing had low mortality, both before and after litter equalization, compared with the other 2 treatments. In comparison with previously reported results where less than 50% of sows were classified as low mortality (Hales et al., 2014), the proportion of sows with low mortality was generally high. Because this study was conducted in a newly built herd, the sows in this study were relatively young and this distribution across younger parities could have influenced the results as an increase in parity has been shown to increase preweaning mortality (Jarvis et al., 2005; Weber et al., 2009). In this study, first parity sows had lower mortality than sows of parity 2 and sows of parity 3 to 4 from litter equalization to d 4. First parity sows are smaller and lighter than older sows, which could influence their ability to stand and lie down in a controlled way, and they have likewise been found to be more responsive to piglet distress calls (Hutson et al., 1992). First parity sows also have shorter duration of farrowing than older sows (Tummaruk and Sang-Gassanee, 2013), indicating that the physical strain of the farrowing process is prolonged and harder to recover from in older sows.

The design of the SWAP pen incorporated to a large extent the recommendations for pen design proposed by Baxter et al. (2012) and was planned to provide the newborn piglets with a thermally adequate environment and protect them from crushing by the sow. Without the option of confinement, the production results in these pens were poorer compared with traditional crates (Hales et al., 2014), but the outcome from this study shows that by use of a strategy for temporary confinement, piglet mortality can be considerably improved. However, this questions the need for confinement throughout lactation as it is practiced in traditional farrowing crates.

The 3 production systems were compared within the same herd. This within-herd approach has previously been used in studies comparing piglet mortality in crated and penned sows in commercial settings (Cronin et al., 2000) whereas system performance has also been studied across herds (KilBride et al., 2012). When herds with different systems are compared, an effect of housing system is possibly confounded by an effect of management or other herd factors. By comparing systems within a herd, effects of herd factors were minimized and the differences in mortality could be attributed to the system. As with any other system, variations in mortality across herds should be expected if the systems investigated in this study are implemented in other herds.

In conclusion, the results from the current study highlight the importance of the time from birth to litter equalization when discussing piglet mortality and suggest that confinement of sows when the last piglet is born does not improve perinatal mortality. Confinement for the first 4 d of lactation did reduce piglet mortality in that period, but the lowest piglet mortality was achieved when sows were confined before farrowing and for 4 d after farrowing, suggesting that live-born piglets are at risk also during the farrowing process. Based on the current study, temporary confinement of sows for a short period before and after farrowing seems necessary to reduce piglet mortality.

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